Geomatrix

Memorandum

TO:	Mark Thompson	**DATE:**	March 23, 2006
FROM:	Jeff Weaver	**PROJ. NO.:**	7753
CC:		**PROJ. NAME:**	Red Dog Water Balance Study
SUBJECT:	**Red Dog Water Balance Considerations**		

Appendix C, Section I, Part A of the EPA Fact Sheet on the Red Dog Mine NPDES permit presents an estimate of the general water balance related to the tailings impoundment and discharge from the impoundment, and concludes that "there is some flow into the impoundment that is unaccounted for in attempting to explain the rise in water level in the impoundment" (page 44). Geomatrix Consultants, Inc. developed a detailed water balance model for the impoundment beginning in 2002. The model uses daily measurements of all water balance inflow and outflow components to estimate the water level in the impoundment. The model includes both climate variables (precipitation, evaporation, and temperature) along with measured flows from tailing production to estimate pond stage with a high degree of accuracy. Based on data and analysis performed during development of the detailed daily water balance model, all inflow and outflow components to the impoundment are considered well known and well characterized.

A key consideration for development of the daily water balance model was the understanding that daily measurements of both precipitation and evaporation included bias and needed to be corrected for actual site conditions. Measurement bias is a basic and common consideration when analyzing meteorological data, as discussed in the following sections.

Precipitation

Biases in precipitation measurements occur due to both the methodology used to measure precipitation (i.e. precipitation gauges) and the spatial location of the recording station. Based on an assessment of data available at Red Dog, biases due to both of these conditions is evident in the data.

Measurement biases

Precipitation measurements using standard gauging approaches are subject to various errors, with a general tendency toward measurements that under-record actual precipitation (Linsley, et al,

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1982). This is especially true in windy environments and in areas with significant snow fall (Larson and Peck, 1974). Under-measurement of precipitation in general and snow in particular at meteorological stations in Alaska has been widely studied for many years (Black, 1954, Benson, 1982, and Yang, et. al. 1998). A recent study by Benning and Yang (2004) was focused on developing daily adjustments of measured precipitation data for the National Weather Service (NWS) stations at Barrow and Nome, Alaska, over a 7-year study period, from 1995 through 2001. The results of this study indicate that the bias adjustments increase the average monthly gage-measured precipitation by approximately 20%–180% for Barrow and 30%–380% for Nome, with the larger percentages occurring in winter months. Calibration of the Red Dog daily water balance suggest that gauge measurements may under-measure snow fall by up to 40 %.

Spatial location biases

In mountainous terrain, precipitation and snow fall is generally higher at higher elevations (Chua and Bras, 1982). In general, meteorological stations that are located in the valley areas likely do not produce measurements that can be accurately applied at a watershed scale. This phenomenon has been widely studied, and several methods for assessing watershed-scale precipitation totals based on limited station measurements have been developed (Chua and Bras, 1982, Day, 1990, Phillips et al., 1992, Daly and Neilson, 1992, McManamon, et al., 1993, Hartman, et al., 1995, and Hartman, et. al, undated). At Red Dog, manual measurements of snow pack depth at various areas in the watershed indicate that snow fall may be under-measured at the meteorological station by 10 to 30 %.

Calibration of the daily water balance for the Red Dog tailing impoundment shows that snow precipitation is under-measured by approximately 40 %, while rainfall during summer months measured with reasonable accuracy. Thus a snow-undercatch factor of 1.4 is applied to all precipitation measured during the winter months. As noted, the under-measurement of snow precipitation is attributed to a mixture of both gauge and spatial biases when applied at the scale of the watershed. Table 1 presents a summary of both measured annual precipitation values and estimated actual precipitation.

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Table 1 – Annual Precipitation at Red Dog Mine, 1992 - 2004

Year	Measured Precipitation (inches)	Estimated Actual Precipitation (inches)
1992	14.8	17.2
1993	19.7	22.7
1994	26.3	28.4
1995	14.8	16.8
1996	16.9	18.6
1997	16.2	18.0
1998	20.4	22.1
1999	11.5	12.6
2000	21.7	23.4
2001	19.0	20.6
2002	20.7	23.6
2003	19.3	22.0
2004	20.3	22.4

Evaporation

Evaporation is measured at Red Dog using a standard pan approach, in which total monthly evaporation is estimated based on the amount of water evaporated from a large pan at the Bons Creek meteorological station. Significant evaporation only occurs during the summer months. Water in the pan will evaporate at a greater rate than from the surface of tailing impoundment. This is because the pan will be warmed much more readily by solar radiation than the surface water in the impoundment (Fetter, 1994). The main reason for this discrepancy is the difference between the water depth in the pan versus depth of water in the impoundment. The pan can also gain or lose heat through the sides and bottom, a process that does not occur in the impoundment. Therefore, a pan coefficient factor of less than one is applied to the pan data to estimate the amount actual evaporation from open water in the impoundment (Fetter, 1994). Pan coefficients vary widely based on local geography, temperature, and wind conditions. Estimated values across the United States vary from 0.13 to close to 1.0 (Houman, 1973). At Red Dog, calibration assessments using the daily water balance model suggest a pan coefficient of approximately 0.50 is appropriate for the tailing impoundment. Estimated annual evaporation totals are provided in Table 2.

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Table 2 – Annual Evaporation for the Red Dog Mine, 1992 through 2004

Year	Estimated Evaporation (inches)
1992	7.84
1993	8.29
1994	5.675
1995	6.215
1996	Not Measured
1997	5.84
1998	7.245
1999	7.405
2000	7.535
2001	6.015
2002	5.6575
2003	5.734
2004	6.7435

Because the drainage areas providing water to both the tailing pond and mine areas (feeding the mine sump) are known with great accuracy, the amount of water entering the pond from precipitation runoff and discharging via evaporation can be calculated with great accuracy. Therefore, all inflows and outflows from the impoundment are well known, and there are no "unknown" sources of water as stated on page 44 of Appendix C.

Groundwater Conditions

It is important to note that no significant groundwater inflows occur into the impoundment, and that impoundment inflows are derived primarily from and are thus proportional to precipitation falling on the tailing and mine drainages. The assumption of 100 % runoff of estimated actual precipitation is sufficient to account for all inflows into the impoundment. The absence of a significant shallow groundwater flow system was a key finding of a seven year $3.5 million dollar Supplement Environmental Program (SEP) study performed at Red Dog under a Consent Decree with the EPA. The groundwater and permafrost environment at Red Dog was characterized through data collected from over 50 thermistors and 25 piezometers installed around the tailing impoundment and throughout the mine during 1995 through 1999. Results of this program were presented in numerous reports (Water Management Consultants, 1997, 1999, and 2001) to EPA. The findings of the studies were approved by EPA in 2001, resulting in an ongoing program of permafrost and groundwater monitoring that continues to collect and analyze subsurface temperature and deep groundwater level data (Geomatrix Consultants, 2003, 2004, and 2005).

The results of these studies showed that the active layer at Red Dog is generally less that 15 feet thick and thaw occurs only during July, August, and September. Since the ground is frozen to the surface most of the year, shallow groundwater flow can only occur during the short period of thaw during the summer. Because of the shallow thaw depths and small saturated thicknesses, there is little active groundwater flow at a regional scale (Water Management Consultants, 1997, 1999, and 2001).

Please call me at (303) 534-8722 if you have any questions or comments.

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